A Calderon Multiplicative Preconditioner for PEC Structures Containing Junctions

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Among all integral equations pertinent to the analysis of scattering from three-dimensional perfect electrically conducting (PEC) surfaces, the Electric Field Integral Equation (EFIE) remains the most widely used. Unfortunately, the EFIE operator is ill-posed as its eigenvalues accumulate at zero and infinity. For this reason, the linear system matrix that results upon discretization of the EFIE using boundary elements is highly ill-conditioned whenever the surface mesh is dense. The need for dense surface discretizations commonly arises when analyzing electromagnetic phenomena on structures with sub-wavelength geometric features, e.g. millimeter and microwave integrated circuits, antenna feeds and beam-forming networks, aircraft fuselage details, etc.

The literature abounds with techniques to precondition EFIEs. One such technique, the Calderon Multiplicative Preconditioner (CMP) (F. P. Andriulli et al., IEEE TAP, 56(8), 2398-2412, 2008) can be trivially integrated into existing boundary element codes as the discretized operator comprises the multiplication of two standard EFIE matrices (produced with a standard Rao-Wilton-Glisson code) weighted by sparse Gram and projection matrices that contain only O(N) nonzero elements. Recently, a generalized CMP was developed that casts the standard CMP into a fully algebraic framework and applies to arbitrary meshes, expansion orders, and basis functions while no longer requiring the explicit construction of dual basis elements (F. P. Andriulli, F. Valdes, K. Cools, E. Michielssen., Proc. AP-S, 1-4, 2010). Unfortunately, neither standard nor generalized CMPs apply to PEC structures containing junctions. The reason can be traced to the fact that the continuity of a piecewise linear polynomial function defined over two of the three surfaces of a PEC junction is not necessarily maintained when the function is extended to the third surface.

This paper demonstrates that this problem can be solved in the framework of the generalized CMP by suitably modifying the projections spaces that the generalized CMP acts on. More specifically, it is shown that, by appropriate symmetrization of the degrees of freedom (in the projection spaces' bases) that have a junction in their domain, the continuity of piecewise linear polynomial subsets of the projection spaces is always maintained for any choice of junction surfaces. Numerical results will show the effectiveness of the proposed approach in accelerating the convergence of EFIE solvers applied to densely meshed structures containing junctions.